When and where did hybridization occur? The case of the Monte Capanne Pluton, Italy

D.S. WESTERMAN[1], A. DINI[2], F. INNOCENTI[3] AND S. ROCCHI[3]

1. Department of Geology, 158 Harmon Drive, Norwich University, Northfield, Vermont 05663
2. Istituto di Geoscienze e Georisorse – CNR, Via Moruzzi 1, Pisa, I-56124, Italy
3. Dipartimento di Scienze della Terra, Via Santa Maria 53, Università di Pisa, Pisa I-56126, Italy

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ABSTRACT

The Monte Capanne pluton was emplaced during the Late Miocene in a post-collision extensional regime that generated the Tuscan Magmatic Province as the Adriatic (lower) plate underwent progressive crustal delamination. This dominantly monzogranitic pluton, generated by hybridization between mantle and crustal magmas, consists of mappable facies; end members range from less hybridized with high concentrations of very coarse K-feldspar megacrysts and abundant mafic microgranular enclaves, to more hybridized with low megacryst and enclave abundances. K-feldspar megacrysts from Monte Capanne and other related units of the province, along with their inclusions and associated late mineral phases, preserve evidence of chemical and $^{87}Sr/^{86}Sr$ disequilibrium (first rising and then falling) during evolution of the system. The concomitant occurrence of contrasting reaction microtextures in accessory phases in this anatectic-hybrid pluton, particularly involving monazite-(Ce), also suggests transient chemical conditions. The ubiquitous mafic microgranular enclaves, typically with high concentrations of xenocrysts from Monte Capanne magma, provide evidence of a highly dynamic system involving vigorous interaction between mafic and felsic magmas. The data suggest that rapid dehydration melting, driven by intrusions of fractionating mantle-derived magma near the base of the crust, was followed by magma mixing and K-feldspar megacryst growth. Segregation and ascent produced the hybridized products now observed at the emplacement level.

RÉSUMÉ

L'intrusion du pluton du mont Capanne est survenue au cours du Miocène tardif dans un régime d'extension de post-collision ayant produit la province magmatique de Toscane au fur et à mesure que la plaque (inférieure) de l'Adriatique a subi une delamination crustale progressive. Ces plutons principalement monzogranitiques, produits par hybridation entre les magmas mantéliques et crustaux, sont constitués de faciès cartographiables; les membres d'extrémité varient des membres peu hybridés renfermant de fortes concentrations de mégacristaux de feldspath potassique très grossiers et d'enclaves microgranulaires mafiques abondantes à des membres plus hybridés comportant de faibles abondances d'enclaves et de mégacristaux. Les mégacristaux de feldspath potassique du mont Capanne et des autres unités apparentés de la province, de même que leurs inclusions et leurs phases minérales tardives associées, préservent les indices d'un déséquilibre chimique et de $^{87}Sr/^{86}Sr$ (d'abord hausse, puis baisse) pendant l'évolution du système. La présence concomitante de microtextures à réactions opposées au cours de phases accessoires dans ce pluton anatectique-hybride, mettant en scène en particulier de la monazite-(Ce), permet par ailleurs de supposer des conditions chimiques transitoires. Les enclaves microgranulaires mafiques ubiquistes, présentant généralement des concentrations élevées de xénocristaux du magma du mont Capanne, témoignent d'un système extrêmement dynamique présentant une interaction prononcée entre les magmas mafiques et felsiques. Les données laissent supposer qu'une fusion à déshydratation rapide, animée par les intrusions de magma mantélique s'étant fractionné près de la base de la croûte, a été suivie d'un mixage de magma et de la croissance de mégacristaux de feldspath potassique. La ségrégation et l'ascension magmatiques ont fourni les produits hybridés maintenant observés au niveau de l'intrusion.

[*Traduit par la rédaction*]

INTRODUCTION

Interaction of partially molten materials (hybridization) commonly occurs in the crust when mantle-derived magma provides the heat for crustal melting. This interaction begins as early as the onset of anatectic melting in the source region, with direct interaction between the magmas or incorporation of enclaves into the crustal melt, with diffusion across contacts, and phenocryst transfer between mafic and felsic magmas. In addition to interacting, such melts can evolve independently as well. Dehydration melting of crustal sources is commonly accompanied by growth of crystals that are products of dehy-

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dration reactions; those products remain as part of the evolving magmatic system. Crystallization can also occur either continuously once a phase is nucleated, or intermittently, depending on changes in P-T-composition conditions either in the melt zone, during ascent, at any resting levels temporarily occupied, or in the final emplacement level. And finally, the intrusion of mantle-derived magmas, crustal melting, magma extraction, and emplacement can occur in simple steps or in a complex pattern spread through both space and time. Clearly, magmatic systems producing granitoids need to be examined holistically, from source to final exposure (Petford *et al.* 2000), or from «cradle to grave».

Several crustal- and mantle-derived melts were involved in the generation of the intrusive and extrusive units making up the Tuscan Magmatic Province (TMP) of central Italy (Dini *et al.* 2002; Innocenti *et al.* 1992). The Monte Capanne pluton is made up of a range of hybrid products derived by modification of one of these anatectic melts, along with another group of products derived by modification of mantle-derived magmas. Hybrids dominated by the crustal melts are expressed by the various facies of the Monte Capanne pluton, whereas the mafic magma hybrids are represented by the ubiquitous presence of a wide variety of mafic microgranular enclaves. In this paper, we explore how a detailed petrographic, geochemical, and isotopic study of such a complex system can document processes in the source area that created a broad variety of products long before these materials ever reached their emplacement levels.

GEOLOGIC AND TECTONIC SETTING

Regional geology

The Monte Capanne pluton is located on Elba Island at the northern end of the Tyrrhenian Sea (Fig. 1), a region affected by extensional processes behind the eastward-progressing front of the Apennine mobile belt. The backbone structure of the Apennines was constructed when the Sardinia-Corsica block collided with the Adria plate (Malinverno and Ryan 1986). This orogenic system evolved diachronously (Fig. 2) as the extensional regime migrated from west to east, trailing the retreat of the compressive regime (Brunet *et al.* 2000) and giving way to the opening of the ensialic back-arc Tyrrhenian basin.

Igneous activity associated with extensional processes also migrated from west (14 Ma) to east (0.2 Ma) as the west-dipping Adriatic plate delaminated and rolled back to the east (Serri *et al.* 1993). Intrusive and extrusive rocks that represent hybrids of crust- and mantle-derived magmas built the TMP, spreading over about 30 000 km^2 in southern Tuscany and the northern Tyrrhenian Sea (Dini *et al.* 2002; Innocenti *et al.* 1997; Poli 1992; Westerman *et al.* 1993). Individual intrusive units vary in their compositional ranges, as well as in the range of compositions of their included mafic microgranular enclaves. Variability of the products making up this province has been well documented, particulaly with the use of $^{143}Nd/^{144}Nd$ vs. $^{87}Sr/^{86}Sr$ studies (Dini *et al.* 2002).

The geology of Elba Island

Pre-intrusive setting

The structure of Elba Island consisted of five tectonic complexes (Fig. 1) that were stacked onto each other by about 20 Ma (Deino *et al.* 1992). The lower three (I-III) have continental features, consisting of metamorphic basement and shallow-water clastic and carbonate rocks, whereas the upper two (IV-V) are oceanic in character (Keller and Pialli 1990; Pertusati *et al.* 1993; Trevisan 1950). In more detail, Complex IV consists of Jurassic oceanic lithosphere of the western Tethys Ocean and its late Jurassic-middle Cretaceous sedimentary cover, all deformed and metamorphosed during the Apenninic compression to form east-verging folds. Complex V consists of Paleocene to middle Eocene flysch, overthrust by an upper Cretaceous flysch sequence (Keller and Pialli 1990).

The intrusive sequence

Extensional processes and igneous activity affected Elba Island during the late Miocene (Bouillin *et al.* 1993; Jolivet *et al.* 1994; Serri *et al.* 1993). Field, petrographic, and geochemical data, along with intrusive relationships, have been used to define several Miocene intrusive units in western and central Elba and to correlate them between exposures (Dini *et al.* 2002). Ranges of composition are reported in the total alkali vs. silica (TAS) diagram (Fig. 3; Le Bas *et al.* 1986) to illustrate overall chemical compositions of the intrusive units. The relative chronology of the intrusive sequence has been firmly established on the basis of crosscutting relations supported by isotope chronology (Dini *et al.* 2002). The magmatic sequence led to the formation of a nested Christmas-tree laccolith complex with a total thickness of about 2400 m of porphyritic rocks emplaced at depths of 2 – 3.5 km (Rocchi *et al.* 2002; Westerman *et al.* 2004). This complex was then intruded by the Monte Capanne pluton, portions of which were intruded by the Orano dyke swarm before complete consolidation.

The first episode of magmatism, with products derived completely from a felsic source (Dini *et al.* 2002), occurred around 8 Ma. This episode started with emplacement of the Capo Bianco porphyritic aplite, with alkali feldspar granite composition, followed by the Nasuto micro-syenogranite. Both of these units were then intruded by the younger Portoferraio porphyry with compositions ranging from monzogranite to syenogranite, and prominent phenocrysts of sanidine. This much more voluminous intrusion formed the Christmas-tree laccolith made up of four major layers which are interconnected and accompanied by minor dykes and sills. All together, this episode of magma-

Fig. 1 Geologic map and cross section of Elba Island. Abbreviations: SMF is the main feeder dyke for the San Martino laccolith; EBF is the Eastern Border fault; CEF is the Central Elba fault; ZF is the Zuccale fault.